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Microgrid Adoption Patterns in Portugal and the U.S.

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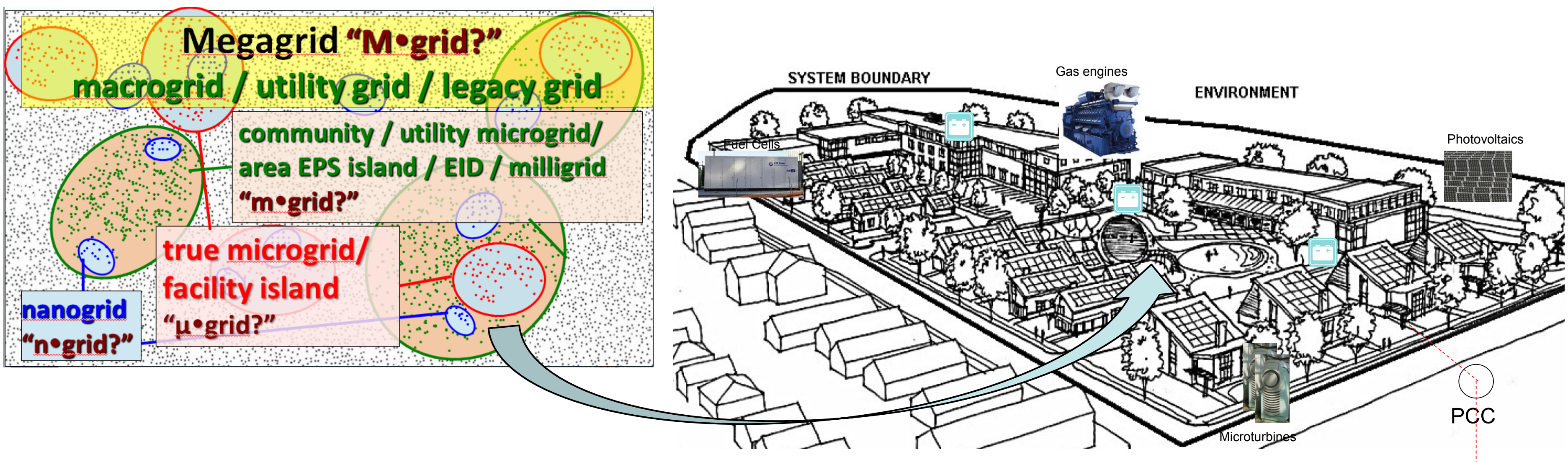
Focus on "milligrids", maximizing integration

Community-scale power systems that meet the requirements for a microgrid, or "***milligrids***" where numerous types of demand meet, can potentially increase microgrids' benefits by making use of **synergies between different kinds of customers**



opportunity to explore demand patterns

About 30% of World microgrid pilots are community-scale

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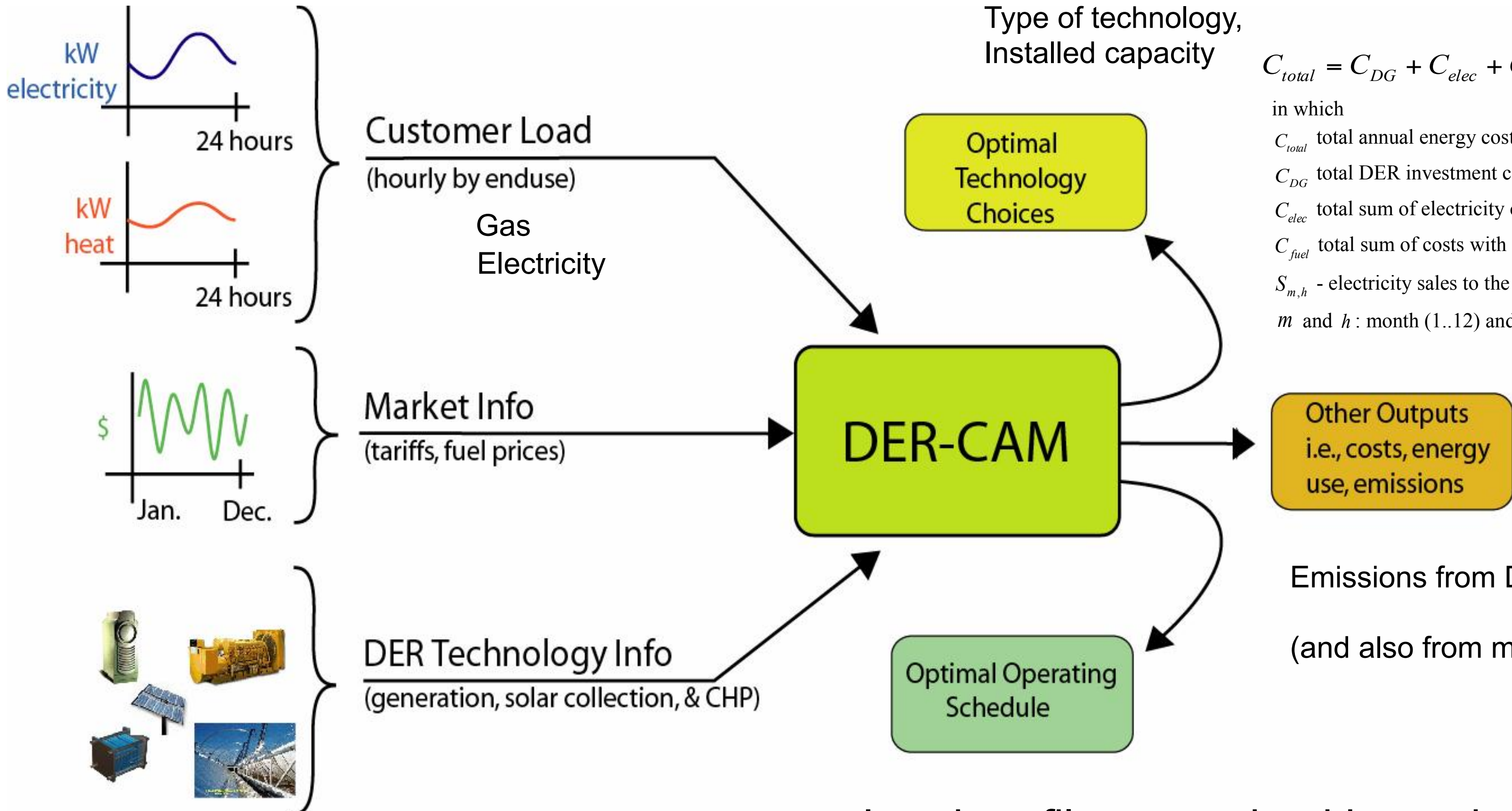
Study of microgrids' adoption patterns

What circumstances can make community-scale microgrids attractive investments in the urban context?

1. analyzing how differently and **under which patterns** distinct building types or its combinations could invest in microgrids
2. identifying **energy costs** and **environmental impacts** under different demand mixes and explore sensitivities to regulatory and environmental aspects (demand, climate, tariff structure

This research intents to fill the gap of sectorial regulatory and policy directions for a rapidly-emerging microgrid market and to sustain future planning and deployment decisions.

Microgrid optimization tool – DER-CAM



Type of technology,
Installed capacity

$$C_{total} = C_{DG} + C_{elec} + C_{fuel} - \sum_{m} \sum_{h} S_{m,h}$$

in which

C_{total} total annual energy costs of microgrid, in USD,

C_{DG} total DER investment capital cost, in USD,

C_{elec} total sum of electricity costs in USD,

C_{fuel} total sum of costs with fuels in USD,

$S_{m,h}$ - electricity sales to the macrogrid in USD,

m and h : month (1..12) and hour (1..24) indexes.

Emissions from DER

(and also from macrogrid)

Load profiles organized by end-uses: **electricity-only**, **space-heating**, **cooling**, **water heating** and **gas-only**.

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Microgrid configuration optimization

Extension of DER-CAM to accommodate optimization of community-scale, multiple-building microgrids

$$\sum_{i=1}^{n} Load_{i\in\aleph} = Load_1 + Load_2 + .. + Load_n$$

$$\sum_{i=1}^{n} ElLoad_{i\in\aleph} = \sum_{i=1}^{n} ElOnlyLoad_{i\in\aleph} + $$
$$+ \sum_{i=1}^{n} CoolLoad_{i\in\aleph} + \sum_{i=1}^{n} RfLoad_{i\in\aleph}$$

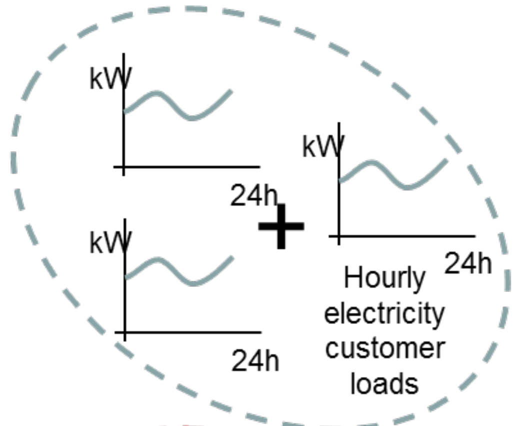
$$\sum_{i=1}^{n} NGLoad_{i\in\aleph} = \sum_{i=1}^{n} SpaceHeatLoad_{i\in\aleph} + $$
$$+ \sum_{i=1}^{n} WtHeatLoad_{i\in\aleph} + \sum_{i=1}^{n} NGOnlyLoad_{i\in\aleph}$$

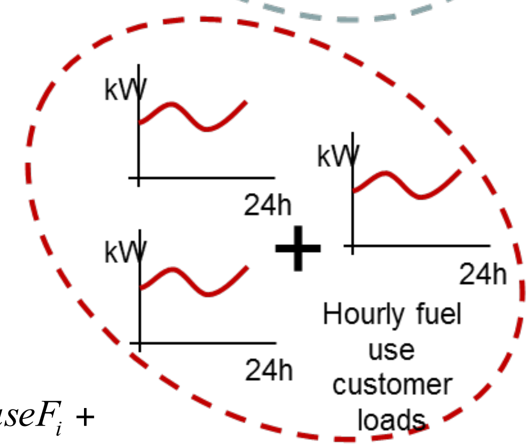
$$CERTS\,\text{cost} = \left[\left(CostM \cdot Switchsize \right) + \sum_{i=1}^{n} CostB_i \right]$$

Allowing for specific definition of building loads and microgrid critical requirements

UP TO 3 loads

PQR Requirements:
HTL, SCH: 10% critical loads
OFF: 25% critical loads
HOSP: 50% critical loads



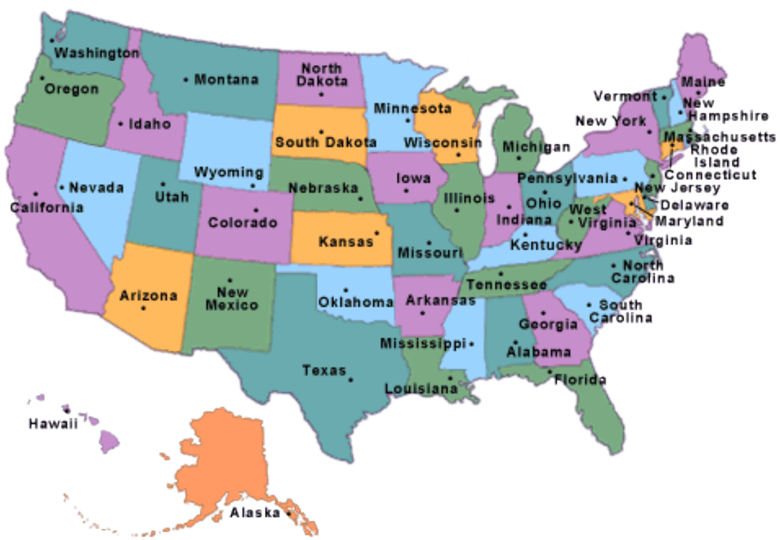


$$Switchsize = \sum_{i=1}^{n} \left[\min\left\{ ElLoad_i \right\} \cdot BaseF_i + \right.$$
$$\left. + \left(\max\left\{ ElLoad_i \right\} - \min\left\{ ElLoad_i \right\} \right) \cdot PeakF_i \right]_i$$

Case-study applications

The analysis of microgrids economic adoption patterns is done for different contexts

USA: Load data based on the compiled U.S. Department of Energy (DOE) commercial reference buildings models



Portugal: Data collection work in collaboration with several energy services companies

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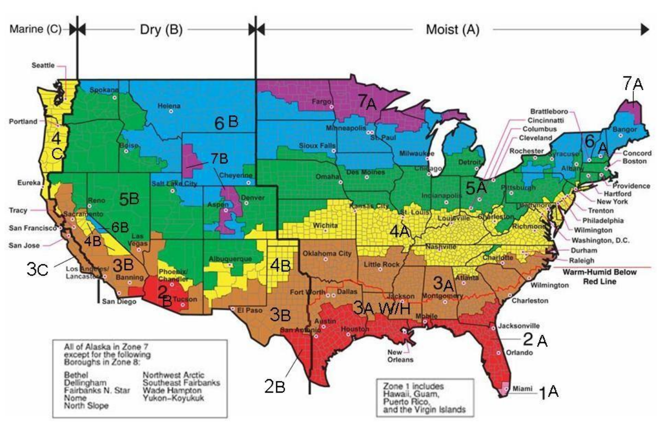
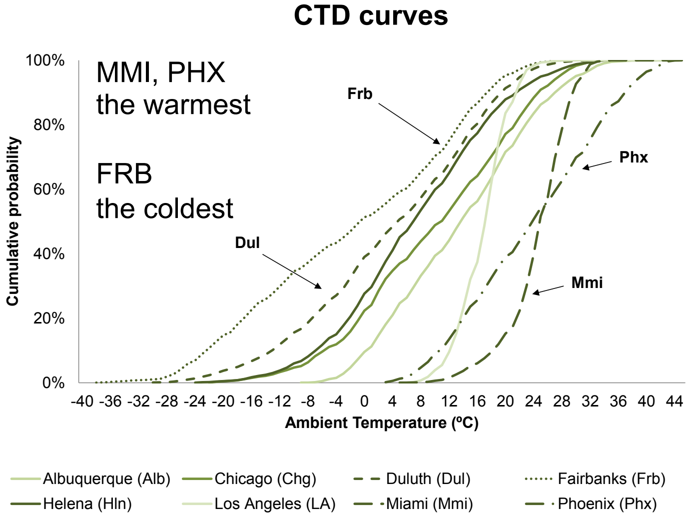
Description of the U.S. case-study

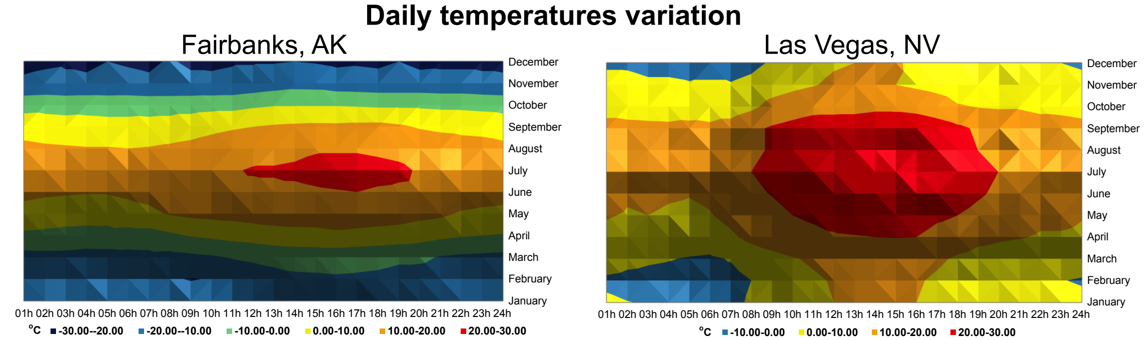
- Runs in 8 representative cities, located in each one of the U.S. climate zones, developed by ASHRAE
- The entire set of building loads is based on the compiled U.S. DOE commercial reference buildings models
- The commercial and residential prototype buildings models were simulated in EnergyPlus in order to obtain the final DER-CAM load profiles

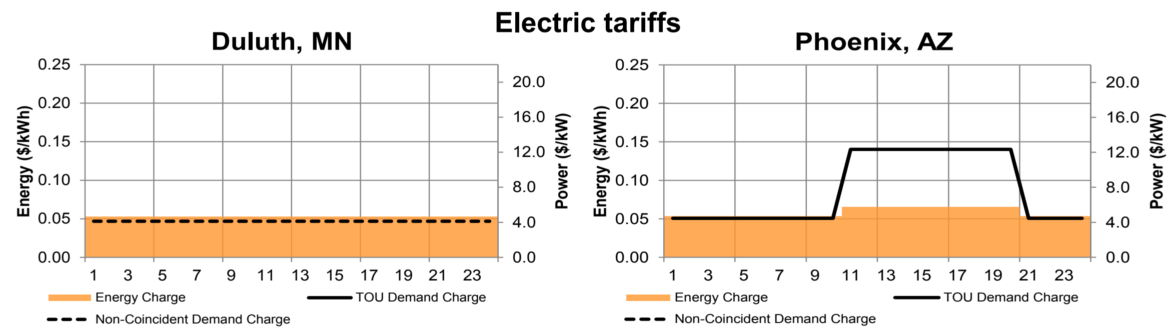


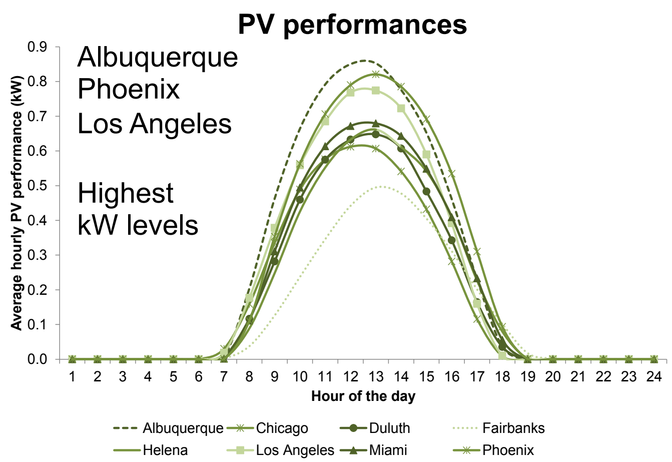
Representative city	State	Climate Zone
Miami	Florida	1A
Phoenix	Arizona	2B
Los Angeles	California	3B – Coast
Albuquerque	New Mexico	4B
Chicago	Illinois	5A
Helena	Montana	6B
Duluth	Minnesota	7A
Fairbanks	Alaska	8A

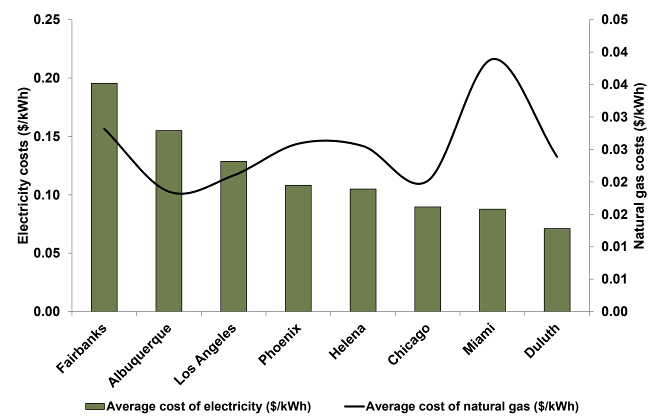
U.S. case-study ,climatic and regulatory diversity











L.RES: 30un. Midrise. Apt., Secondary school, 10un. Full-service restaurant;

L.SRV: Small hotel, 10un. Quick-service restaurant, 5un. Strip Mall;

L.OFF: 2un. Large offices, 5un. Quick-service restaurant, Small hotel.

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U.S. case-study, optimal technology mix

Optimal technology mix of large microgrid adoption solutions in U.S. representative cities

	ICE (kW)	PV (kW)	ST (kW)	ES (kW)	Abs (kW)	Switch (kW)
Albuquerque						
RES	810 (CHP)	0	0	0	898	130
SRV	310 (CHP)	4	0	0	189	67
OFF	1000 (CHP)	279	0	0	517	445
HOSP	500 (CHP)	115	0	0	208	472
Chicago						
RES	500 (CHP)	0	0	0	78	159
SRV	60 (CHP)	39	0	0	0	67
OFF	560 (CHP)	0	0	0	124	516
HOSP	560 (CHP)	0	0	0	85	525
Duluth						
RES	120 (CHP)	0	0	89	0	128
SRV	60 (CHP)	0	0	54	0	66
Fairbanks						
RES	810 (CHP)	0	0	0	300	91
SRV	310 (CHP)	0	0	162	37	54
OFF	1060 (CHP)	0	0	162	377	414
HOSP	560 (CHP)	0	0	0	130	408

	ICE (kW)	PV (kW)	ST (kW)	ES (kW)	Abs (kW)	Switch (kW)
Helena						
RES	500 (CHP)	0	0	0	342	116
SRV	120 (CHP)	0	0	0	0	62
OFF	500 (CHP)	0	0	5	293	427
HOSP	500 (CHP)	0	0	0	108	441
Los Angeles						
RES	1000 (CHP)	0	0	0	662	135
SRV	370 (CHP)	0	0	0	266	77
OFF	1120 (CHP)	0	0	0	616	449
HOSP	620 (CHP)	0	0	0	208	558
Miami						
RES	250 (CHP)	0	53	0	375	167
SRV	60 (CHP)	0	49	155	104	80
OFF	250 (CHP)	0	45	138	257	260
Phoenix						
RES	250 (CHP)	0	0	0	571	174
SRV	60 (CHP)	79	0	111	132	93
OFF	500 (CHP)	227	0	0	336	535
HOSP	560 (CHP)	109	0	290	125	606

- All runs invest in CHP ICEs, in RES areas to cover very high heating needs of apartments, schools and restaurants
- OFF and HOSP, reliability-intense areas, invest more in DER capacity and with less climate sensitivity than RES and SRV

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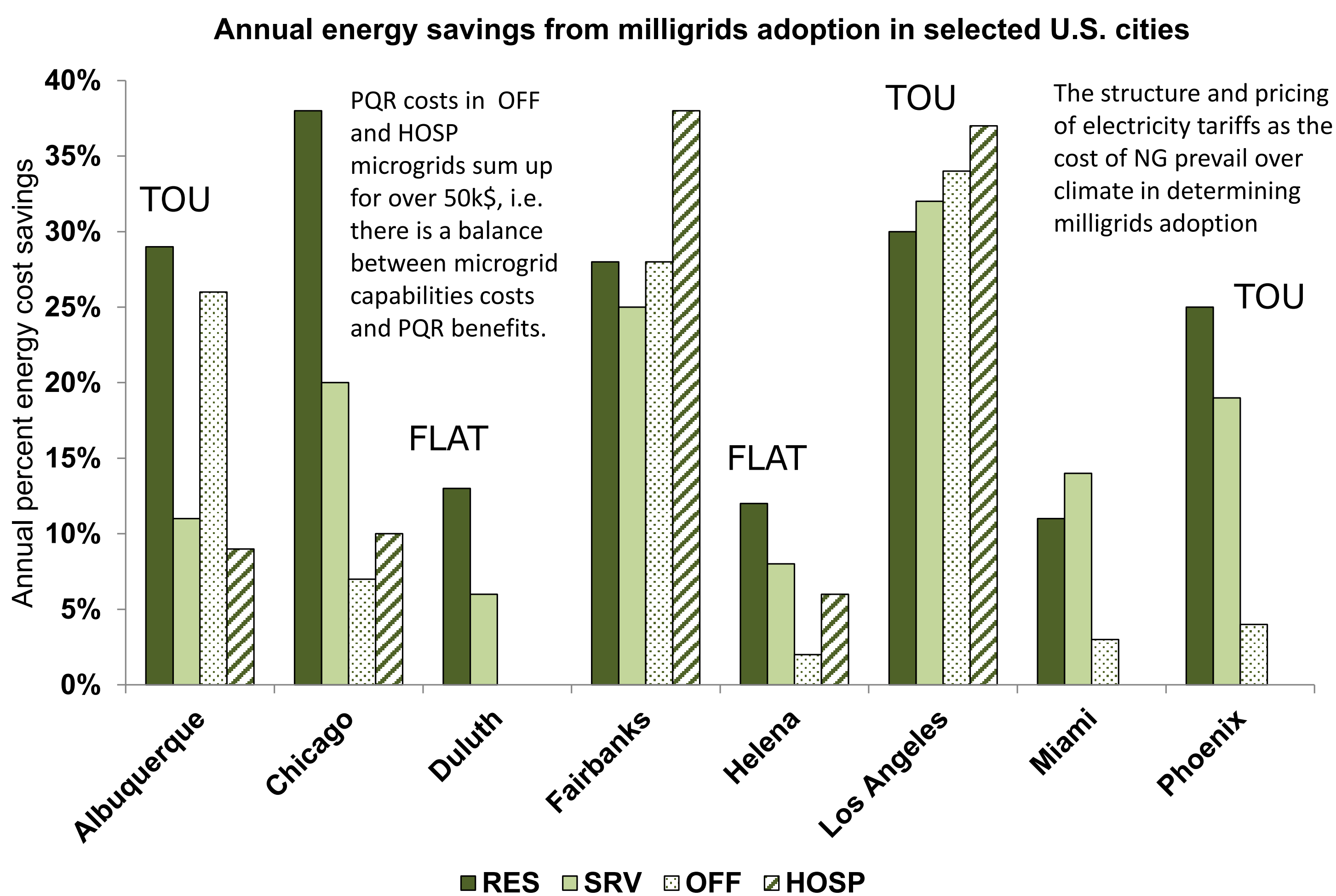
U.S. case-study, annual energy savings



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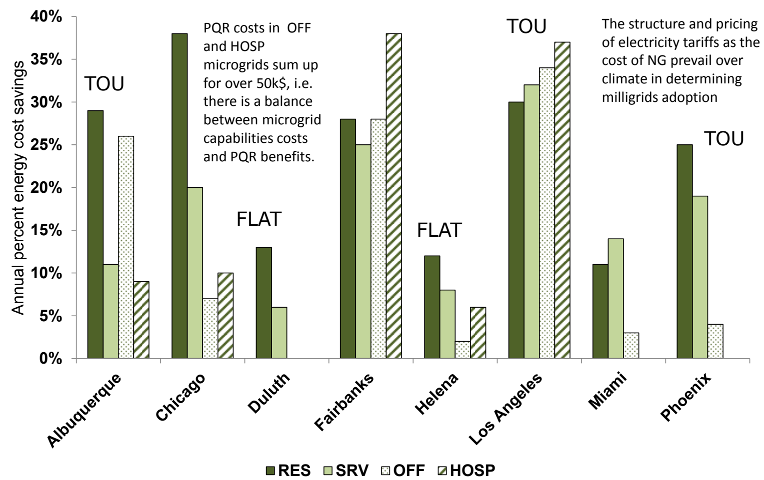
U.S. case-study, annual energy savings

- Limited investments and savings in cities with **cheap electricity**, **expensive NG** or no **TOU**
- Helena, Miami, Duluth with savings <10%, 5%



- **Warmer vs. colder climates:** Group composed of Albuquerque, Los Angeles, Miami and Phoenix with average energy cost saving of 18% against 13% for the group composed of Chicago, Duluth, Fairbanks and Helena

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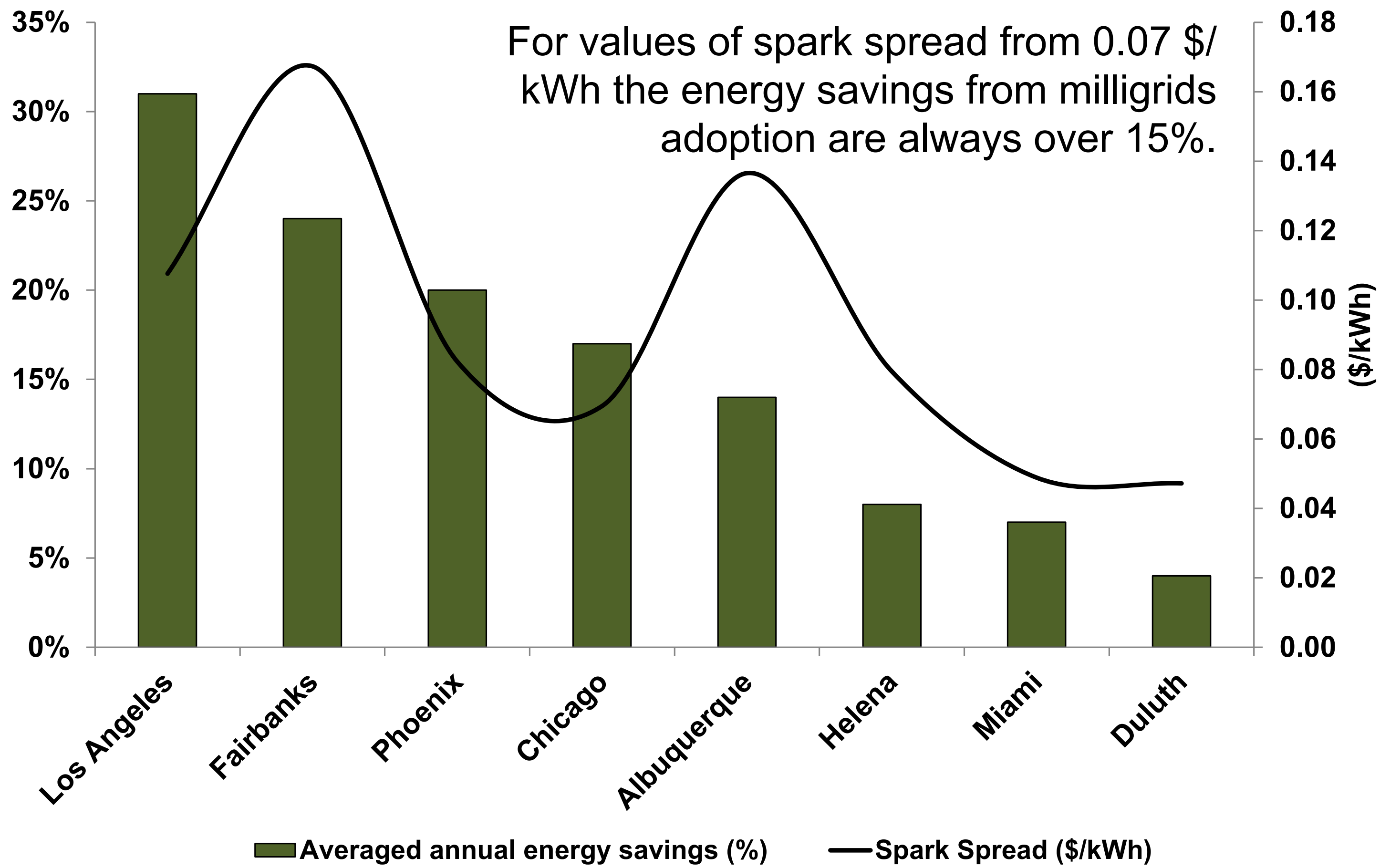
U.S. case-study, spark spread analysis

Spark spread vs. savings analysis for large microgrids adoption in U.S. representative cities.



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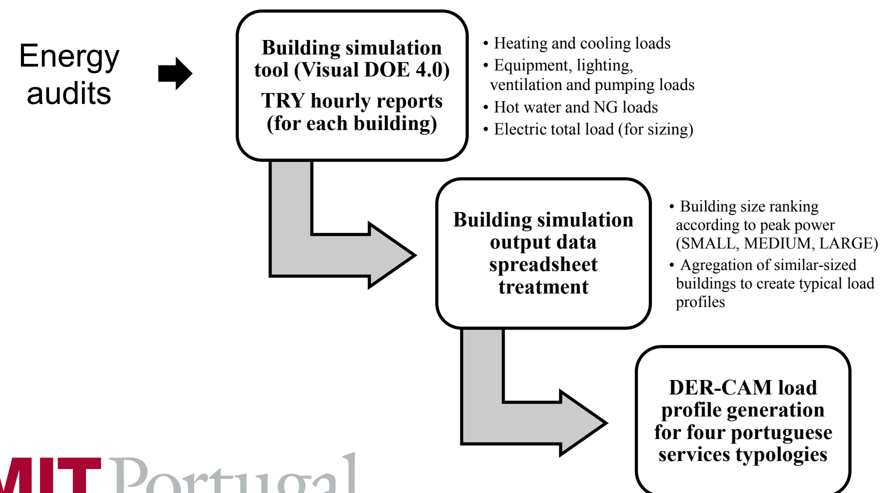
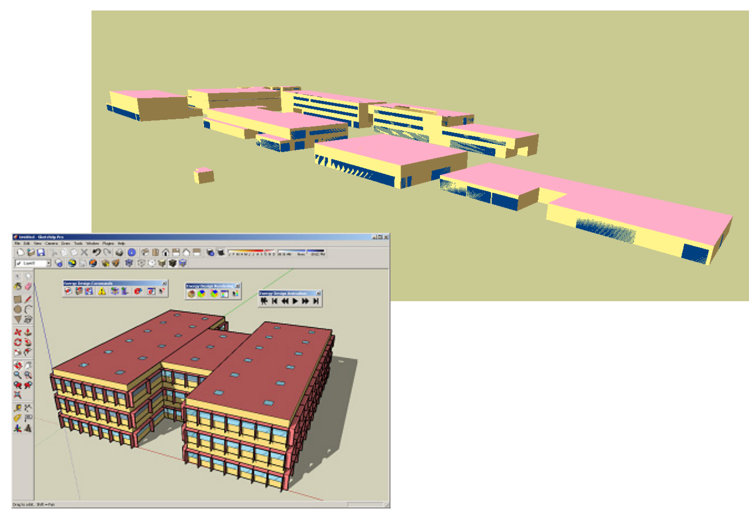
Description of the Lisbon case-study

- DER-CAM models were created that reflect technological, environmental and market conditions in Lisbon, Portugal
- Collection of residential and commercial buildings load data in the region of Lisbon and creation of typical building profiles
- The simulation tools Visual DOE 4.1.2 and E+ are used to run building models and obtain hourly reports, inputs to DER-CAM





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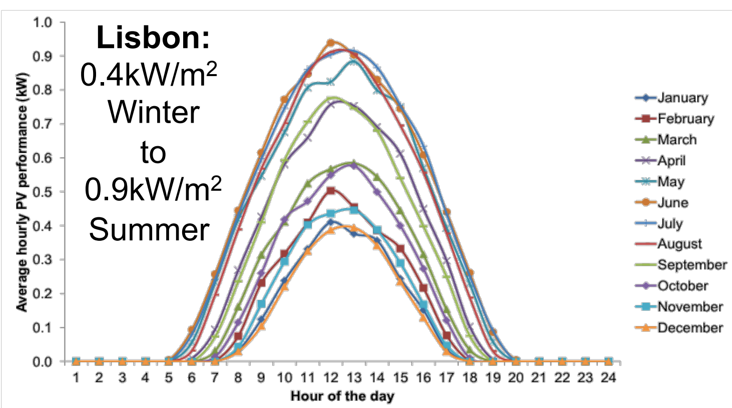
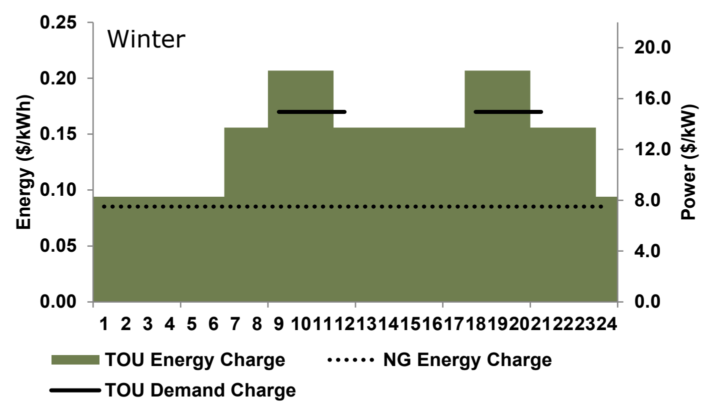
Lisbon case-study, milligrids' adoption runs

Four distinct building types and a residential area are analyzed in order to access microgrid customer adoption patterns

	RES	LODG	EDUC	OFF	HLTH
Electrical peak load (kW)	769	830	896	968	1207
Electrical load factor (%)	12%	33%	20%	36%	50%
HPR (%)	55%	17%	46%	11%	20%
Heat/Elec. Coincidence (%)	27%	13%	20%	11%	20%





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Lisbon case-study, optimal technology mix

Optimal technology mix of microgrid adoption solutions in Lisbon

	ICE (kW)	PV (kW)	ST (kW)	ES (kW)	HS (kW)	Abs (kW)	Switch (kW)
RES	0	51	17	55	0	0	18
RES+SCH	60 (CHP)	335	83	0	0	260	110
RES+HTL	250 (CHP)	222	146	0	449	116	104
RES+OFF	250 (CHP)	489	98	0	455	222	283
RES+HOSP	500 (CHP) + 60	693	200	77	527	140	691
SCH	0	291	73	217	0	249	92
SCH+HTL	250 (CHP)	593	160	0	473	372	178
SCH+OFF	250 (CHP)	697	145	0	553	503	356
SCH+HOSP	750 (CHP)	443	257	0	645	516	765
HTL	0	351	61	359	0	64	86
HTL+OFF	250 (CHP)	701	123	0	490	302	351
HTL+HOSP	750 (CHP)	577	246	0	582	320	759
OFF	250 (CHP)	361	10	0	0	258	265
OFF+HOSP	750 (CHP)	1058	153	0	477	399	938
HOSP	500 (CHP) + 60	433	247	317	868	128	673

- Investment in CHP ICEs, except for RES, SCH and HTL
- When high-reliability needs exist → investment in ICE capacity

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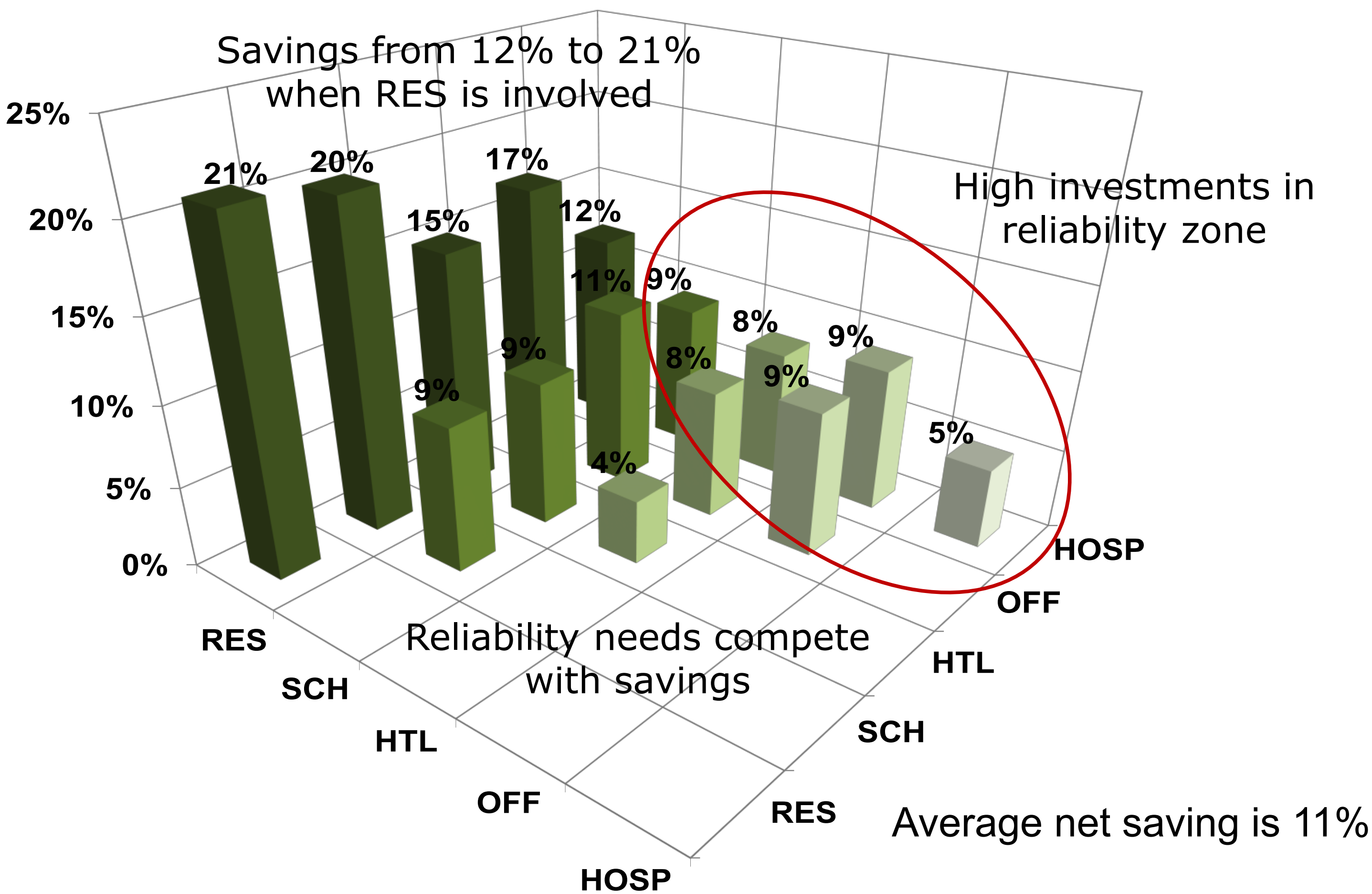
Lisbon case-study, annual energy savings



Average net saving is 11%

Bigger savings when RES areas are involved

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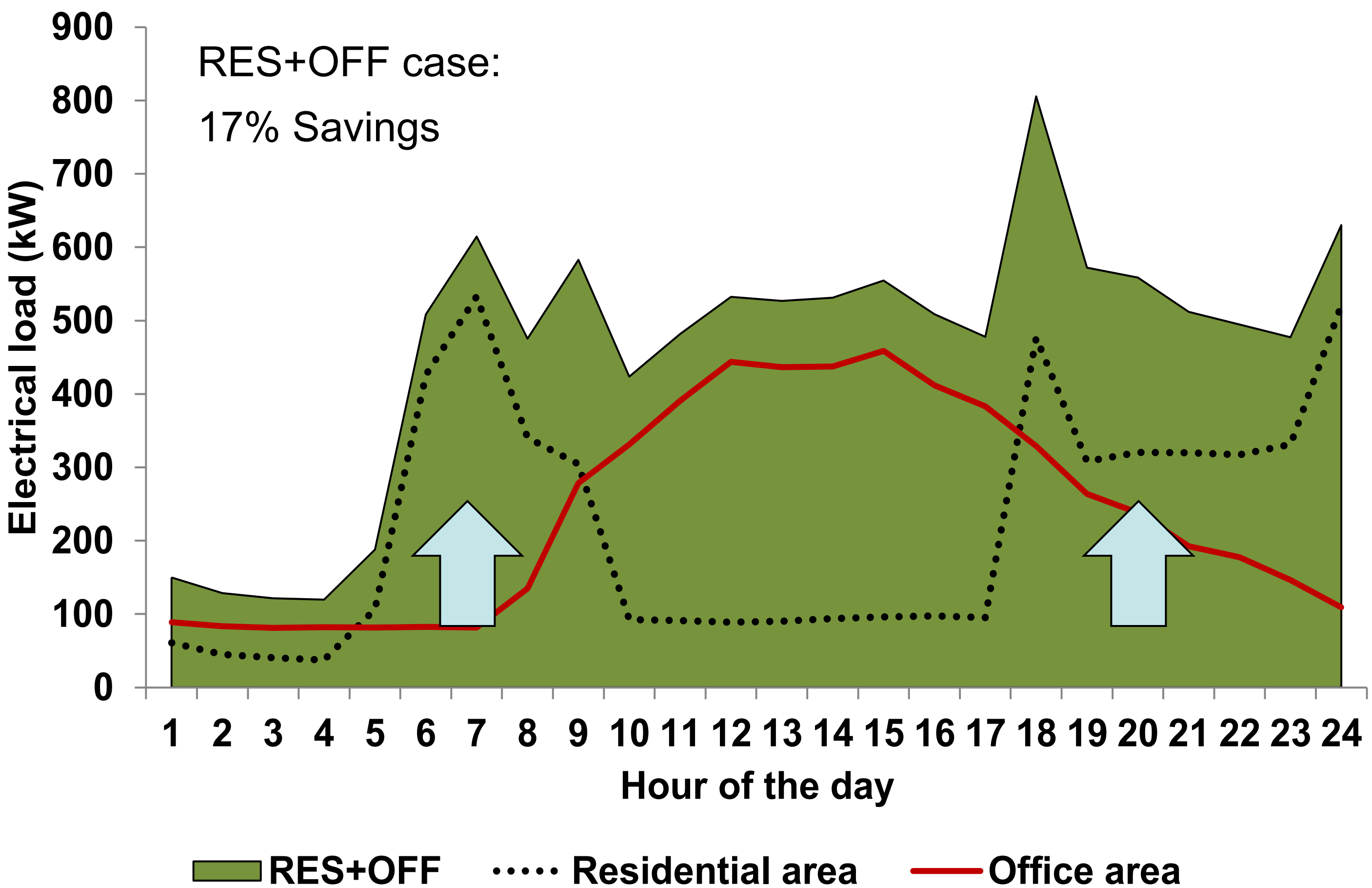
Lisbon case-study, complementarity of loads

- Allows better use of generation assets!



Example electrical daily profile

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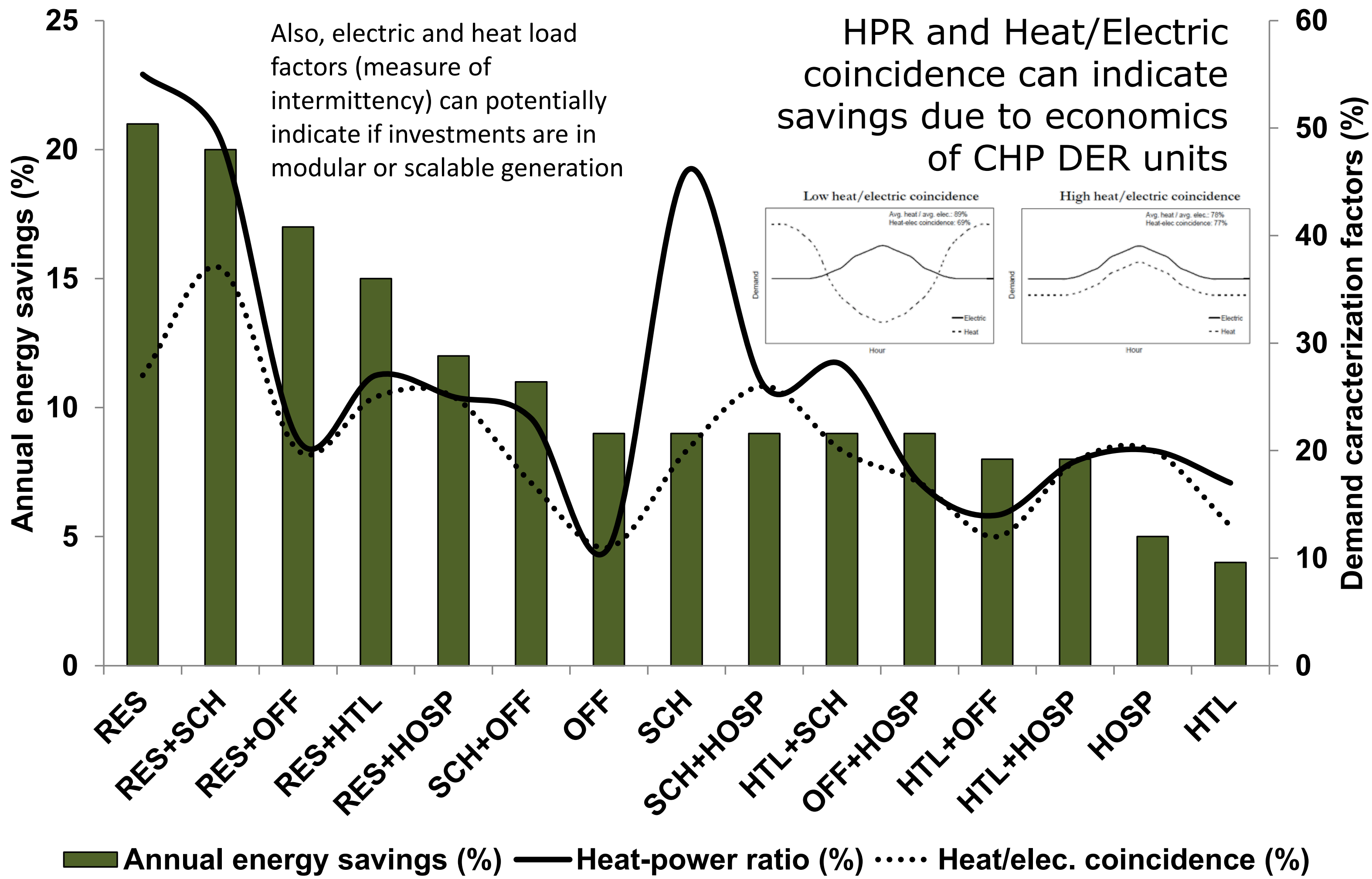
Lisbon case-study, demand characteristics



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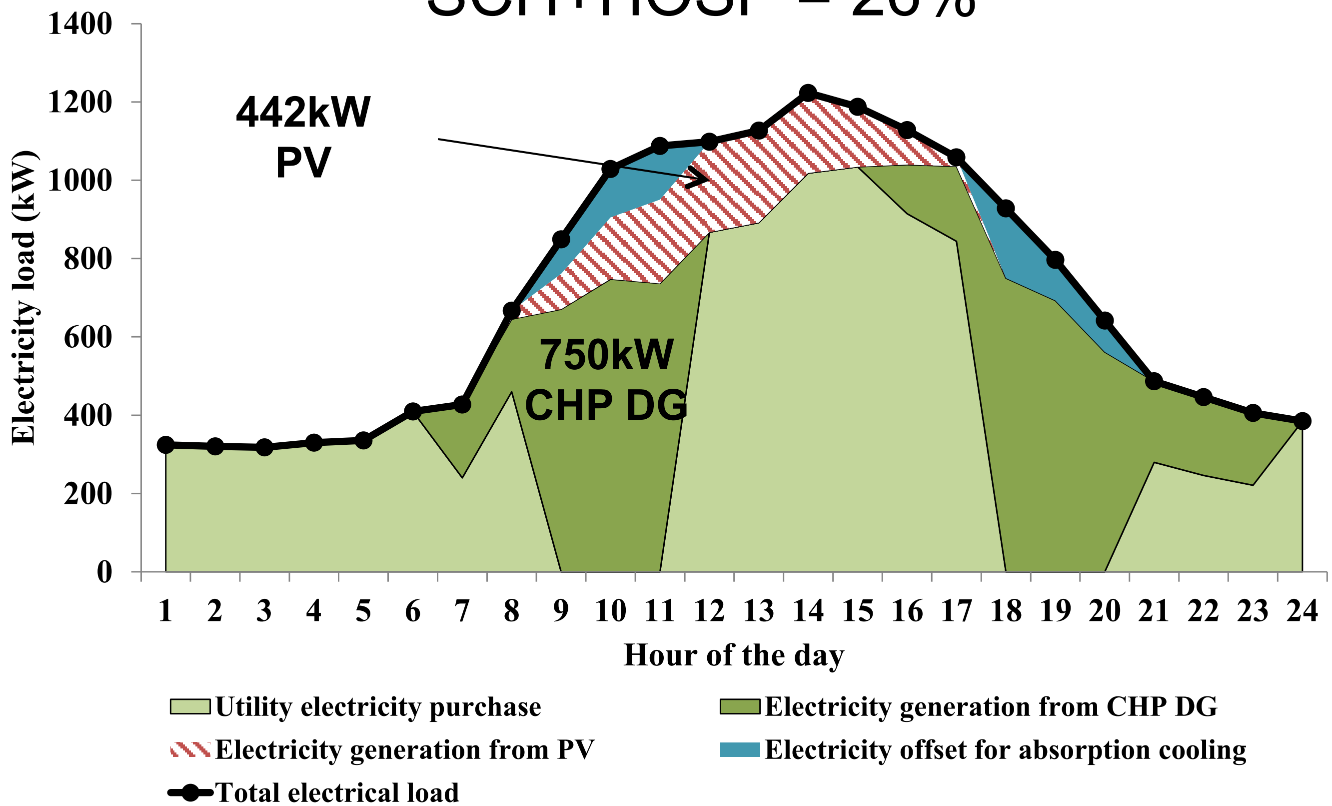
$$\text{Heat/elec. coincidence} = \frac{\sum_{i=1}^{8760} min\{kW_{thi,} kW_{ei}\}}{\sum_{i=1}^{8760} kW_{ei}}$$

Lisbon case-study, H./E. coincidence example

TWO peak periods:

Operation is directed to avoid energy and power charging during expensive hours of the early morning and late afternoon.

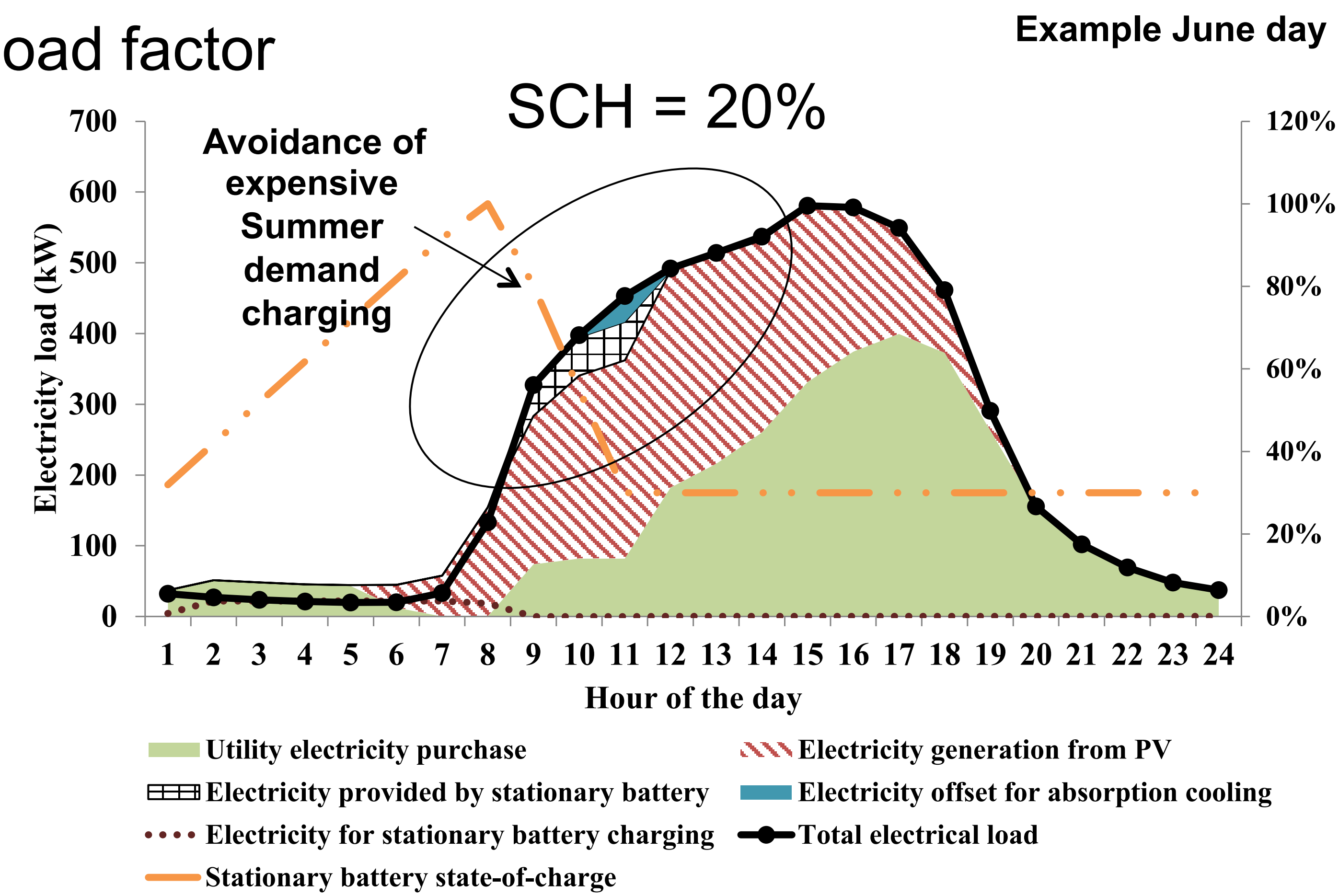
Heat/electric coincidence
SCH+HOSP = 26%



Example December day

Lisbon case-study, electric load factor example

Electric load factor



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Investment in scalable technologies such as lead-acid batteries and PV covers the low load factors of the EDUC profile

Conclusions

- Microgrids and specifically milligrids can constitute feasible investments in the majority of climates but are generally more attractive in warmer regions, with larger availability of DER.
- The pricing and structure (TOU or flat) of tariffs as well as the energy pricing spark spread prevail over the impact of climate as the factors mostly determining microgrids adoption.
- The PQR requirements of a given urban area are a determinant of the level of adoption of DER prime-movers and infer on the energy savings. Still, there's a balance between costs and benefits of PQR, allowing customers to invest economically in highly reliable microgrids.
- Residential areas show increased sensitivity to climate in relation to any commercial area and bear special interest to milligrids due to the complementary nature of its load profile. Any other aggregation of complementary loads is in principle economically beneficial.
- Office and hospital areas represent demanding, not always appealing, milligrid investments.
- "Lightweight" services areas make generally attractive milligrids investments in all climates.
- Hotel, residential and school buildings, where PQR needs are reduced or non-existent, are susceptible to microgrid investments characterized by purchase of PV, ST and battery storage. Offices and hospitals in opposition require the purchase of more reliable ICEs.
- HPR as well as H/E coincidence can impact on technology selection and energy savings in microgrid investments. Demand load factors can indicate in which types of DER to invest.

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THANK YOU
(Questions are very welcome!)

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